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A MAN-MACHINE INTERFACE FOR ENERGY MONITORING AND CONTROL SYSTEMS--ETC(U)

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CIVIL ENGINEERING LABORATORY  
Naval Construction Battalion Center  
Port Huachuca, California

Sponsored by  
Naval Material Command

**A MAN-MACHINE INTERFACE FOR ENERGY MONITORING  
AND CONTROL SYSTEMS**

June 1981

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An Investigation Conducted by  
Georgia Institute of Technology  
Electronics and Computer Systems Laboratory  
Engineering Experiment Station  
Atlanta, Georgia

F33615-77-C-2004

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# A Man-Machine Interface For Energy Monitoring and Control Systems

## SECTION I. INTRODUCTION

### Background

An energy monitoring and control system (EMCS) is a system designed to implement the concept of computerized energy management. Since late 1976, an effort has been underway in DoD to develop a tri-service guide specification to be used by government procurement officers as an aid in preparing contract specifications for acquisition of an EMCS. This guide specification covers all work associated with providing shop drawings, plans, equipment, labor, materials, engineering, technical supervision, and transportation necessary to furnish and install a fully operational EMCS. The Navy Civil Engineering Laboratory at Port Hueneme, California, is assisting the Naval Facilities Engineering Command and the Army Corps of Engineers (Huntsville District) with preparation of the guide specification.

### Objective

The objective of this research effort was to address that portion of the specification associated with providing an interface between the EMCS and a human operator. The goal of the effort was to define an appropriate operator interface and provide recommendations for the required interface that would be incorporated into the guide specification.

### Scope

The system/operator interface definition is a function of the desired goal of the installed system, the size of the system under consideration, and the level at which the system and operator communicate. An EMCS may be installed with any one of several goals in mind, such as limitation of peak power usage, overall daily reduction of energy usage, smoothing of hourly surges and lapses in energy demands, etc. The guide specification is

intended for general application and thus does not attempt to address specific goal optimized systems. Accordingly, the research did not consider interface specification differences associated with specific system applications and goals. The guide specification includes discussion of three sizes of systems--small, medium, and large. The number of data points monitored define the size of a given system. The necessity for and level of system/operator interface will vary as a function of system size. This research focused on the most difficult problem of operator interaction with large systems.

It is presumed that three skill levels of individuals might interact with a fielded EMCS; programmers or systems analysts, engineers, and watch supervisors or operators. Programmers or systems analysts are primarily concerned with maintenance and upkeep of EMCS software. They can be assumed to have a high level of skill in dealing with computer systems so that providing for a "friendly" interface environment is not so important at this level as with the other two types of system operations personnel. Specifications for programmer/system analyst interface with EMCS were not addressed by this effort. Since engineers and watch supervisors or operators are both likely to have less skill at interacting with real-time computer systems than programmers or analysts, the research emphasized the needs for interfacing between the system and the two lower skill levels, especially the operator level.

## SECTION II. PROBLEM DESCRIPTION

### EMCS Description

By definition, an EMCS is an energy management system which employs off-the-shelf minicomputers, microcomputers, associated peripherals, instrumentation, control equipment, and application programs written in high level languages such as FORTRAN, BASIC, or Pascal, configured into a network with control functions at multiple locations and a central point of operator control and supervision.<sup>1</sup> EMCS's are classified into four categories related to the total number of monitor-control points connected to the system:

- Large EMCS                      in excess of 2,000 points
- Medium EMCS                    500 to 2,500 points
- Small EMCS                     100 to 750 points
- Micro EMCS                    less than 125 points

The large EMCS pictured in Figure 1 consists of a central control unit (CCU) (with its associated computer (CPU) memory, and input/output (IO) devices), a central communications controller (CCC), a communications link terminator (CLT), field interface devices (FID), multiplexer panels (MUX), intelligent multiplexer panels (IMUX), instrumentation, and controls. The CCU contains a minicomputer or microcomputer (CPU), with main memory for operating system software and implementation of energy conservation programs, and auxilliary mass storage memory for recording data. The CPU executes optimization algorithms used to predict environmental conditions and rate of power consumption, calculate equipment operating points, and produce control signals to operate equipment in the real-time environment. The alarm and logging printers provide a permanent copy of system operations and historical data. The operator's console is the prime operator interactive element in the system. It accepts operator commands, displays data, and graphically displays systems controlled or monitored by the EMCS. The systems terminal is used to develop programs, run



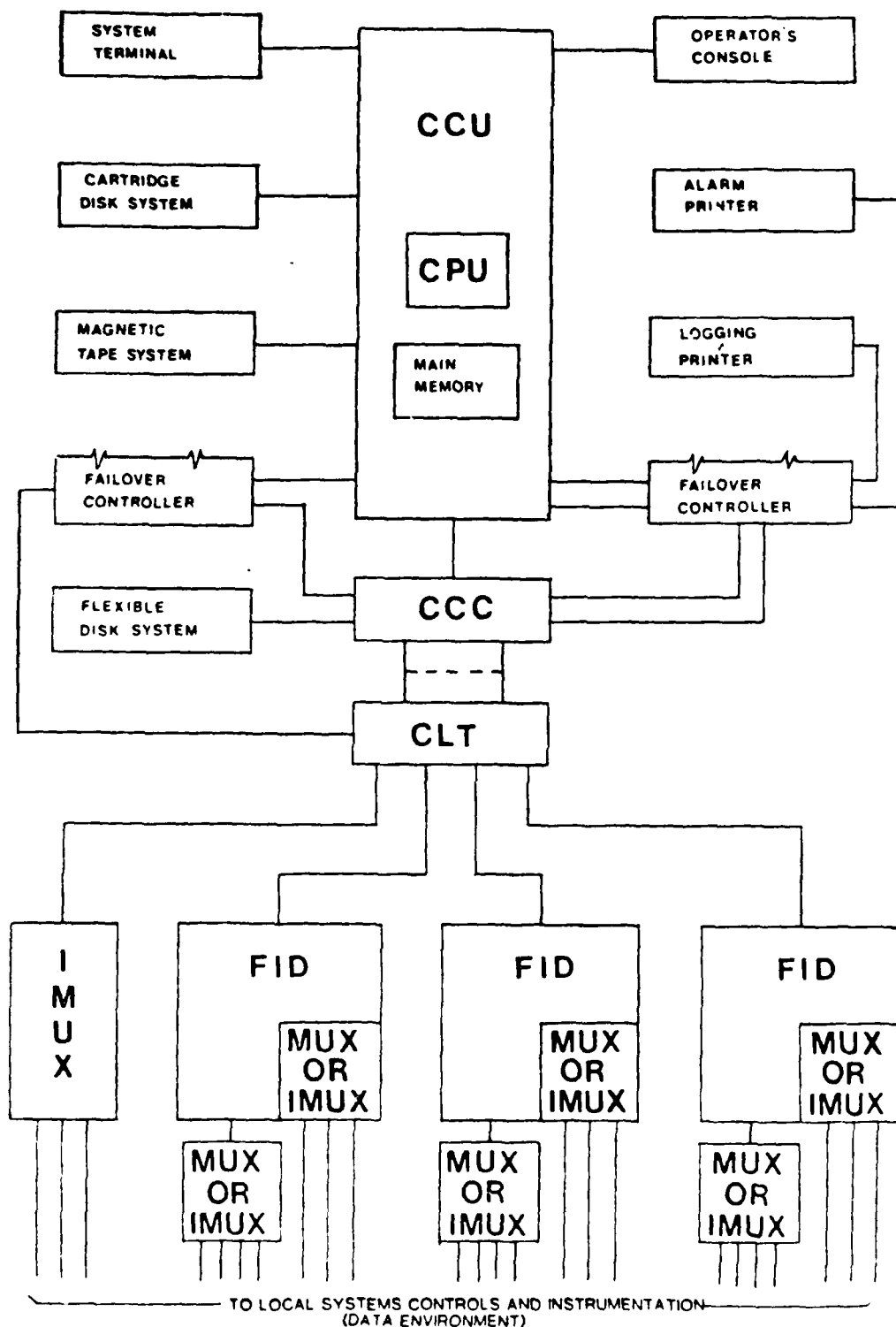


Figure 1. Large EMCS Block Diagram

diagnostics, and support background processing. The CCC is a mini or micro computer with sufficient memory to execute the software required to reformat, transfer, and perform error checks on data between the CCU and the FIDS, and to provide limited backup in the event of CCU failure. The failover controllers are automatic switches which put the system into a backup mode of operation in the event of CCU or CCC failure.

The CLT provides an interface between the CCC and whatever data transmission media (DTM) is used to connect the central system control elements with the FIDS. A FID is a microcomputer based device with memory, I/O and communications capability, and a power supply. The FID provides an interface to the controlled equipment and environment, performs calculations and logical operations, accepts and processes CCU commands, and is capable of stand-alone operation in the event of CCU, CCC, or communications link failure. The collection of sensors and controls attached to a given FID is known as the data environment (DE) for that device. The MUX panel is a hard-wired or microprocessor-based device which combines data from a number of points in a DE, communicates on a single channel, and performs demultiplexing of commands received from the FID.

The MUX panel is functionally a part of the FID and may be in the FID enclosure or remotely located. MUX panels continuously transmit data from the DE to the FID. IMUX panels are similar to MUX panels, but operate in a report-by-exception mode. IMUX panels can perform all functions of a MUX panel and can be substituted for MUX panels. The IMUX panel communicates with the CCC/CCU by exception, thereby limiting the amount of data which must be handled. The IMUX panel scans its DE, compares the data received against the previous values, and reports only the data that has changed.

In summary, the general purpose of an EMCS is to provide for automatic monitoring and control of energy consuming devices so as to optimize and reduce the consumption of energy.

### Operator Functions

While an EMCS is primarily a computer-controlled, self-operating device, there is still a need for human operator intervention. The EMCS does not include the energy consuming devices themselves, such as motors, water chillers, fans, etc. The EMCS monitors and controls these devices and relays an alarm to the operator when a device failure occurs. Operator intervention is required to contact and dispatch maintenance personnel, and possibly to adjust operating modes or controller set points in the EMCS as a result of component failure. Section 12 of the draft Corps of Engineers Guide Specification<sup>2</sup> contains a description of commands which an operator should be able to enter through the operator's console. Consideration of this list will give an appreciation of the scope of operator interaction with the EMCS. In accordance with the draft guide specification, an operator should be able to perform the following tasks.

- Request a display of any digital or analog point or any logical group of related points in the system
- Start up and shut down any selected systems or devices
- Initiate reports
- Request graphic displays
- Modify time and event scheduling
- Modify analog limits
- Adjust set points of selected controllers
- Select manual or automatic control modes
- Enable and disable individual points
- Enable and disable individual FIDs
- Enable and disable individual MUX/IMUX panels

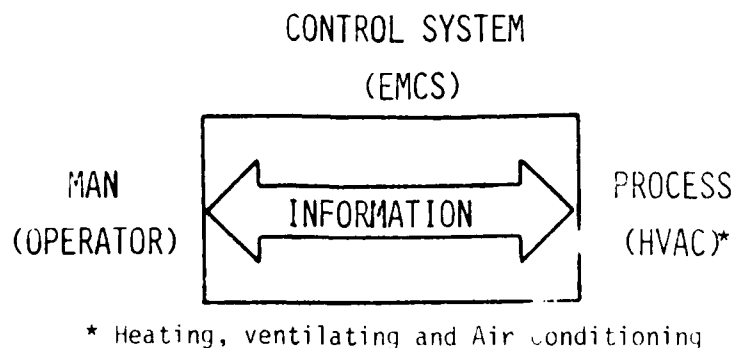
The tasks and interactions described above are the province of the lowest skill level, the watch supervisor/operator category. The next higher skill level is that of the system engineer who would be called upon to make changes in graphic displays, rewrite optimization algorithms, and perform other functions of EMCS maintenance or updating. The guide specification calls for eight levels of system access, with each higher level increasing the allowed interaction by the user. Entry to the various levels is controlled by the use of passwords.

### SECTION III. PROCESS CONTROL AND THE MAN-MACHINE INTERFACE

#### Introduction

Process control and instrumentation have been greatly enhanced during the past twenty years by the incorporation of minicomputers and microprocessors in control systems. In the future this trend will probably continue and may even accelerate in terms of number of application areas and extensions of accuracy and precision. This growing use of computer control systems, with their large information and control data bases, is focussing attention on the problem of interfacing the human operator in the system, with the process under control and the process control computer or system.

The Man-Machine Interface Committee of the International Pipeline Workshop on Industrial Computer Systems defines the man-machine interface (MMI) as the boundary between the human operator subsystem and the machine subsystem across which information and control manipulation flows.<sup>2</sup> In physical terms, the MMI is typically a console which contains displays and keyboards of various types. The hardware and software behind this boundary accomplishes translation of human inputs to control signals and process inputs into data displays for humans. Figure 2 is a simplified depiction of the system and subsystem elements discussed above in terms of the specific process and control system under consideration.



\* Heating, ventilating and Air Conditioning

Figure 2. Man-Machine Interface

In this simple diagram there are three definable interfaces:

1. Control System/Process Interface
2. Man/Control System Interface
3. Man/Process Interface.

The research reported herein restricts itself to the man-control system interface.

### Interactive System Design

Ben Shneiderman, in his recently published book entitled "Software Psychology", has done a credible job in pulling together and giving some framework to a considerable collection of work on design of devices for interaction between human beings and computer systems.<sup>4</sup> Successful industrial design unites required functions and appropriate esthetics while keeping costs low. Providing useful tools to computer users who have a widely varying level of experience, problems, skills and expectations is a challenge to scientific competence and engineering ingenuity, in addition to requiring a measure of artistic talent. Interactive computer-based systems for process control must be carefully designed to provide efficient, safe, reliable and effective service while offering user satisfaction. Regular users quickly pass through the gadget fascination stage and become demanding users who expect the system to aid them in performance of their work.

Unfortunately, there exists no pat algorithm for optimal or even satisfactory design. Interactive system designers must seek a workable compromise between conflicting design goals. Systems should be simple but powerful, easy to learn but appealing to experienced users, and facilitate error handling while allowing some freedom of expression. The diversity of situations in which interactive systems may be used makes it very difficult to define a universal set of goals for system design. Even so, numerous researchers have attempted to prescribe so-called "universal" goal sets. The collection of sets thus introduces into the literature entries which

are not independent and sometimes are in conflict, make contradictory recommendations, and are largely unmeasurable as design goals. If any single consideration is apparent among these various lists, it is the dictum "know the user".

In an attempt to provide an informal integration of this extant body of design principles, Shneiderman has bravely set forth four mostly independent, fairly thorough, interactive system design goals: simplicity, power, user satisfaction, and reasonable cost. An interactive system is said to be simple if it has few commands and if the commands have consistent structure. Command structures should fit the problem domain and user thought processes (know the user). Simple systems are easy to learn, easy to remember, easy to use, and easy to modify and repair. One of the great benefits of using computers is the power they offer. A good system design includes powerful commands which enable users to more easily accomplish their goals. The computerized system must be better in every way than the manual system. User satisfaction is separate from effectiveness. A system may be effective but unpleasant to use, or satisfying but ineffective. The computer should appear as a helpful tool aiding users in the performance of their tasks. A system design which costs too much is a failure.

#### Interactive Interface Issues

A good interactive system not only earns respect and makes the operator want to use it, but it generates satisfying feelings and confidence in ones capacity to use it effectively. Attributes which create the image of a quality system include: ease of learning, ease of use, ease of retention, promptness, reliability, courteousness, help in overcoming difficulties arise, and effectiveness as a tool in solving user problems. There are several critical issues regarding the design of an interface for an EMCS: hardware options, psychological factors, and response time.

Hardware options include such factors as: software, hard displays, manipulation devices, and graphics output, input and interaction.

- **Soft v. Hard Copy**

Hard copy displays provide permanent records of system/operator sessions, whereas soft copy displays provide an electronic window which eliminates cumbersome and costly paper consumption. Hard copy can be produced by noisy impact devices, such as Selectric balls, daisy wheels, cylinders, or a matrix of pins; or by quiet nonimpact thermal, electrostatic or ink spray printers. Imprint clarity and typing surface visibility, which may be obscured by the typing device or cover, play important roles in user acceptability. Soft copy may be provided by a cathode ray tube (CRT), light emitting diodes (LED), liquid crystal diodes (LCD), or a flat plasma screen. Display rates can be thousands of characters per second. Glare from the screen, flickering images, lack of contrast and limited number of lines may detract from CRT usage. However, silent operation, unlimited character sets, blinking, multiple intensity levels, black/white reversal, multi-color, erasing, insertion, cursor action, scrolling, and multiple windows are attractive features. The choice is properly dependent on the application, but lower cost, higher reliability, quieter operations, and higher speeds give the advantage to soft displays.

- **Manipulation Devices**

Manipulation devices are the physical means by which the process operator transmits commands to the control system or process. The goal in designing the manipulative section of a man-machine interface should be to avoid imposing unnatural machine language constraints on the operator. Manipulative actions should reflect as nearly as possible the users common or native language and traditional (stereotyped) process-dependent terminology. Program controlled manipulative devices which interact with electronically-formatted display devices which comprise the display medium for all information used in primary on-line control operations include:

Fixed function keyboards  
Variable function keyboards  
Light pens  
Track balls and joysticks  
Touch Screens  
Speech recognition.

**Fixed Function Keys-**A fixed function key is one which has a single dedicated function, identified by a label affixed on or adjacent to the key top. There are two general types of fixed function keyboards: Universal format (ASCII, etc.), and custom format.

**Variable Function Keys-**A variable function key is one whose function is not fixed, but varies according to display conditions, previous action of another key, etc. Variable-function keyboards utilize a common arrangement of blank keys which may have their labels changed in several different ways.

**Overlays-**sheets on which labels are printed or handwritten and positioned by hand to be adjacent to or over keys.

**Filmstrip keys-**each key can take on any of several legends depending on the positioning of a filmstrip mounted in back of the key.

**Shifting-shift or "mode" keys** are used to change among a fixed set of alternate functions, labeled on or adjacent to keys.

**CRT Labeling-**the most flexible and powerful. The number of labels is virtually unlimited. Operating procedures can be completely self explanatory where current labels follow from previous actions. "Illegal actions" can be eliminated by displaying only those labels pertinent to current display conditions.



**Light Pen**-A light pen is a hand-held device that is used to select a location or symbol on a CRT display by pointing at that location and activating a switch. This identifies the corresponding CRT beam x-y coordinates in the matrix of possible CRT beam positions, which is then decoded to determine the addressed function.

**Track Ball and Joystick**-are a means for positioning a cursor or indicator to a particular part of the CRT screen and thereby indicating in some way the data of that location. The trackball operates by moving the cursor with a rolling ball. Normally any direction is possible. Joysticks come in two types, proportional and incremental. The proportional type uses the stick position to determine the cursor position. Full forward for instance is the middle top of the screen. This stick remains fixed when the operator releases it. The incremental type is much more popular, and determines the angle and rate of cursor movement by the angle and distance from the origin.

**Touch Screen**-A touch screen is essentially the inverse of a light pen. It uses a "passive stylus" (finger, pencil, etc.) for pointing at the desired display position. The pointing actuates one electronically sensitive area in "switch matrix" which is deployed over the display. This is decoded to determine the addressed function in a manner similar to the use of the light pen.

**Voice Recognition**-Computerized techniques are becoming available which can recognize spoken multisyllabic words and phrases with good accuracy. However, numerous restrictions exist on vocabulary, training of machine and man, etc. This technique has been used mostly in nonprocess control environments where the motor response outputs are overloaded (both hands full loading packages, with requirement to describe package to a central data processing system), or not available (control inputs being made over a voice-communications channel).

## ● Graphics Output, Input and Interaction

Perceptual psychologists have demonstrated that imagery can offer a decided advantage over words or numbers, within certain applications. With proper graphic presentation, error rates and reaction time can be substantially reduced. The success of graphics interaction hinges upon adherence to a narrow application domain, natural representation of real world phenomena, and acceptability of the set of operators. Researchers have identified five potential problem areas with interactive graphics applications:

1. Boredom - improper pacing
2. Panic - unexpectedly long delays
3. Frustration - inability to convey intentions or inflexible and unforgiving system
4. Confusion - excessive detail or lack of structure
5. Discomfort - inappropriate physical environment

In an effort to avoid these problem areas, several recommendations have been formulated for interactive system developers.

1. Arrange text and graphic symbols on each presentation to establish an explicit context for user action.
2. When a user process is not known in advance, concentrate on displayable data representations and then design operations to act upon these representations.
3. Design the system to provide an explicit framework for representations. The framework gives a uniformity of structure within which the user can synthesize problem solutions. This framework can be developed even though problems themselves are unstructured.

In summary, an interactive graphics system should provide a familiar representation and standard operations.

Psychological factors include short and long-term memory, closure, attitude and anxiety, and control. Short-term memory processes visual, tactical, auditory and other raw sensory information and holds interpreted units of information for up to thirty seconds. The retention period can be extended somewhat by continued rehearsal. Experiments reported by George Miller (1956) have suggested that information perceived by human beings is limited to a number of units equal to seven, plus or minus two.<sup>5</sup> Long term memory appears to be permanent, although some kinds of information may become more difficult to retrieve as time goes by. Transferring information from short-term memory to long term memory requires time and effort. The process of continuing organization and reorganization of information in long-term memory is poorly understood by researchers, but the seemingly unlimited capacity, durability of knowledge, and rapid recall enable human beings to perform remarkable feats. For graphics terminal interaction, the number seven plus or minus two concept implies that the processing capacity of individuals is limited and in constant danger of being overloaded. Soft copy terminal interactions which start with a display requiring the user to memorize twenty options will probably overload the user's short-term memory. A printed list of options or off-line training to embed the knowledge in long-term memory might be preferable.

One of the byproducts of the limitation on human short-term memory is that there is great relief when information no longer needs to be retained. This produces a powerful desire to complete a task, reduce our memory load, and gain relief. Closure is the completion of a task leading to relief. Since terminal users strive for closure in their work, interactions should be defined in sections so completion can be attained and information released. Every time a user completes editing a line or ends an editing session with an EXIT or SAVE command, there is relief associated with completion and attaining closure.

The pressure for closure means that users, especially novices, may prefer multiple small operations to a single large operation. Not only can they monitor progress and ensure that all is going well, but they can release the details of coping with the early portions of the task. One

informal study showed that users preferred three separate menu lists, rather than three menus on the screen at once. Although more typing and more interactions were required for the three separate menus, the users preferred doing one small thing at a time. With three menus at a time, the information about the first menu decision must be maintained until the system acknowledges or the RETURN key is hit.

Studies have demonstrated that user attitudes can dramatically impact learning and performance with interactive systems. Researchers have shown that novices with negative attitudes towards computers learned editing tasks more slowly and made more errors. Anxiety, generated by fear of failure, may reduce short-term memory capacity and inhibit performance. If users are insecure about their ability to use the system, worried about destroying files or the computer itself, overwhelmed by volumes of details or pressured to work rapidly, their anxiety will lower performance. Mild pressure can act as a motivator, but if the pressure becomes too strong the resultant high levels of anxiety interfere with competent work.

In designing a system for novices, every attempt should be made to make the user at ease, without being patronizing or too obvious. A message telling users not to be nervous is a bad idea. Users will feel best if the instructions are lucid, expressed in familiar terms, and easy to follow. They should be given simple tasks and gain the confidence that comes with successful use of any tool or machine. Diagnostic messages should be understandable, nonthreatening, and low-key. If the input is incorrect, avoid blaming phrases such as 'ERROR 425 - NUMBERS ARE ILLEGAL' and merely state what is necessary to make things right 'MONTHS ARE ENTERED BY NAME'. Try to avoid meaningless, condemning messages such as 'SYNTAX ERROR' and give helpful, informative statements such as 'UNMATCHED RIGHT PARENTHESIS'. Constructive messages and positive reinforcement produce faster learning and increase user acceptance.

A defining force in human behavior is the desire to control. Some individuals have powerful needs to attain and maintain control of their total environment; others are less strongly motivated in this direction and are more accepting of their fate. With respect to using computers, the

desire for control apparently increases with experience. Novice terminal users are perfectly willing to follow the computer's instructions and accept the computer as the controlling agent in the interaction. With experience and maturity, users resent the computer's dominance and prefer to use the computer as a tool. These users perceive the computer as merely an aid in accomplishing their own job or personal objectives and resent messages which suggest that the computer is in charge.

Response time is the time required for a system to respond to a command. Acceptable response times are properly a function of the command type. Typically, interactive system users are not disturbed to wait several seconds for the loading of a file or large program, but they expect immediate response to editing commands or emergency requests. At the same time researchers have shown that increasing the variability of system response time generates poorer performance and lowers user satisfaction. Thus, holding responses to minimize response time variance may actually improve user performance and satisfaction.

Installers of time-sharing systems report user dissatisfaction in two situations where response time variance is a factor. In the first case, when a new time-sharing system is installed and the work load is light, response times are low and users are pleased. As the load increases, the response time will deteriorate to normal levels and produce dissatisfaction. By slowing down the system when it is first installed, the change is eliminated and users seem content. A second case occurs when the load on a time-sharing system varies substantially during the day. Users become aware of the fast and slow periods and try to cram their work into the fast periods. Although this approach does help to balance the load, users tend to make errors while working quickly to beat the crowd. Anxiety is increased, complaints rise, and programmers or terminal users may even be unwilling to work during the slow periods. By eliminating the variance in response time, service is perceived to be more reliable and one source of anxiety can be reduced.

In summary, the interactive-system designer has several goals in considering system response times.

1. Shorter response times are better than longer response times.
2. Variance of response time should be mimimized, even at the expense of some increase in mean response time.
3. System performance should be invariant over time.

## SECTION IV. EXISTING SYSTEMS

### Introduction

An important part of the research conducted involved visits to sites with EMCS's installed. There were three primary goals in conducting the visits:

1. To determine what type of personnel were being employed as operators.
2. To determine what are typical operator functions or responsibilities.
3. To determine what type of operator interface was being employed.

Visits were planned to provide a view of several different commercial and development type systems. Sites visited included Vanderbilt University, Nashville, Tennessee (Honeywell 5600), Warner-Robins AFB (Johnson JC-80), Hurlburt Field, Ft. Walton Beach, Florida (AVCO), and Georgia Institute of Technology (in-house development).

### Georgia Institute of Technology

Georgia Tech's in-house EMCS development project began in late 1977, after the Public Services Commission had placed the Institute under the electrical demand rate structure of the Georgia Power Company. Attempts to identify a commercial system supplier whose product met perceived requirements, at an affordable cost, were not successful. Thus it was decided to develop a system using an in-house team of computer researchers and facilities engineers. The primary objective of the Facilities Management System (FMS) design was to reduce energy consumption. Secondary objectives included improved security through controlled access, and establishment of a facility-wide fire-alarm system. This development program has resulted in a fully functional FMS with the following

capabilities: electric demand limiting, closed-loop process control, time/day scheduling, enthalpy optimization, emergency routines, alarm detection, trend-point system logs and profiles, stand-alone capability, global event initiation, operator interaction, and a high-level plant engineering compiler.

The central system controller is an Interdata 7/32. The principle operator interface is a mono-chrome CRT with a fixed function keyboard. Operator commands consist of coded alphanumeric input via the keyboard. The command structure is heavily computer oriented and bears little resemblance to common user or process control language. Additional development work in this area would be required to make the operator interface friendly to proposed operators.

During development, the system has been attended by computer oriented researchers. The ultimate intent is to have current Institute Physical Plant operators run the system. The Physical Plant operators are knowledgeable in HVAC systems, but have no experience with computer systems operation. Typical operator functions include responding to alarms, adjusting set-points, and controlling air-handlers.

#### Hurlburt Field

The EMCS installation at Hurlburt Field, Ft. Walton Beach, Florida is being performed by AVCO Corporation. The system was designed and specified by Air Force A&E's at Hurlburt. The system consists of a DEC PDP-11/24 minicomputer connected through MUX panels to about 500 points on the installation. Uncertainty of goals in the design phase has resulted in a system which principally performs only HVAC monitoring functions, with no direct automatic control. Air handlers can be manually controlled via the EMCS.

The operator interface will be a CRT, using menu displays and alphanumeric coded commands input via a keyboard. A color graphic CRT is to be included, but the operator will not interact in real time with this



graphics terminal. A major problem of the Base Engineer is locating personnel to fill system operator slots. It is felt that system operation cannot be handled by personnel currently being used in HVAC operations. They are seeking individuals with a background in HVAC and digital computer systems. If such experienced individuals can be located, required salary levels to attract and retain them will be higher than for typical HVAC operators. Due to limited system capability, operator interactions will likely consist of only monitor functions and manual control of air handlers.

#### Warner-Robins AFB

Warner-Robins AFB has a Johnson Controls, Inc. (JC-80) system installed and operating. The installation was begun in September 1972 and turned over to the government for joint occupancy in April 1976. During the first year of operations the system was plagued with reliability problems, but these were solved and the system has been operating satisfactorily since April 1977. The heart of the system is a Modcomp mimicomputer, with a paper tape system. This central computer is tied to about 3,500 points in 25 facilities. The system performs monitor functions on chillers (no control); and provides monitor and control capability on 107 air handler units. Some automatic load shedding, metering, optimized start/stop, enthalpy economizers, and totalization are being incorporated into the operation. The system has an unusually large number of monitor points to help identify and analyze maintenance problems on the connected equipment.

The operator interface to the system is a monochrome CRT with a combination of fixed and variable function keys. The operator controls the system by entering highly structured alphanumeric commands through the keyboard. The system command library contains over 160 distinct entries. There are no graphics provided with the interface. The system is manned on an around-the-clock basis with personnel from the base Systems Management Section. System operators are electrical technicians, and electronics and air conditioning equipment mechanics. It was noted that while these

operators had been trained and had operated the system for some time they had some understandable difficulties in recalling and entering system commands from the considerable command library. Operator functions included responding to alarms, adjusting set-points and other parameters, and manually controlling HVAC devices.

### Vanderbilt University

Vanderbilt University, Nashville, Tennessee, has one of the initial installations of Honeywell's newest building management system, the Delta 5600. This Delta 5600 installation is controlled with a Honeywell Level 6 computer, and is tied to about 1750 points in eight buildings across the campus. The primary motivation behind this system installation was to provide centralized environmental control and fire and security protection for the new high-rise Vanderbilt Hospital and medical research center. This system has some very sophisticated algorithms for elevator control, continuous overpressurization and smoke removal in fire situations, global load shedding to keep the hospital fully serviced with electricity and steam, and many other special routines.

The operator interface is a color CRT, with fixed and variable function keys and graphics capability. Operator interaction with the system is conducted with a top-down menu penetration type, allowing easy access to logical groups and points. Operator commands are in English format and are fairly easy to follow.

The Level 6 computer employs a very flexible graphics mode capability which was provided by Chronatics Corporation. There is a graphics symbol library which makes it easy for even the most unsophisticated user to build graphic system diagrams. The graphic diagrams are not in themselves directly interactive. All operator commands, for both the penetration menu mode and the graphics mode, must be entered via the keyboard.

During normal working hours, the system will be manned by a computer-trained operator. Outside of normal working hours the system will be operated by fire and security personnel, most of whom have no experience with computer operations. The day system operator will respond to alarms and have the ability to change system parameters, modify algorithms, alter graphic diagrams, etc. The off-hours operators will monitor alarms and notify designated knowledgeable maintenance people or the day system operators.

## SECTION V. PROPOSED SOLUTION

### Interface Definition

None of the EMCS's reported upon in the previous section had an operator interface which met all the requirements described earlier for a friendly operator interface. The observed systems met the requirements in varying degrees of course, and the Honeywell Delta 5600 came as close as any to the ideal. However, there is technology available to improve upon the Honeywell operator interface concept, and move closer to an ideal man-machine interface.

An EMCS is viewed as a highly automated process, which by design should not require a great deal of attention by the lowest level operator. However, those operations which the operator does perform must be made as easy and natural as possible so as to enable system operation by non-computer-oriented individuals, such as HVAC mechanics and security guards. The general objective should be to make the operator interface to the EMCS as transparent as possible, i.e., the operator should not be burdened with interface-peculiar manipulations, but should have natural or process-related actions to perform.

Keeping in mind the four basic goals of interactive system design, simplicity, power, user satisfaction, and reasonable cost, the following concept for the tri-service EMCS man-machine interface is proposed. The classical observation that "one picture is worth 10,000 words" is most appropriate when dealing with HVAC process control. HVAC systems are generally represented as schematic diagrams using a standardized set of symbology, as opposed to being described using text or menus of text. Thus, the basic element of the proposed interface is a graphics display. Color plays an important role in HVAC system diagrams, to differentiate between various types of fluid flows, etc. Thus, the proposed interface should have a multi-color graphics capability. So far there has been nothing new proposed, as the Delta 5600 and the Alco systems both have a color graphics capability. The missing element with these systems, and the

proposed feature to be implemented, is direct operator interaction with the color-graphics display. It might be argued that the Delta 5600 system offers direct operator interaction with the graphics display, as operator commands may be entered while graphics are displayed. However, the commands are entered via a keyboard using interface-peculiar alphanumeric inputs. The objective here is to use available technology to make the graphics diagram itself directly interactive with the operator, minimizing use of a keyboard.

Three technologies which come to mind for enabling more direct operator/display interaction are the light pen, voice recognition, and touch screen. The basic concept of a light pen was described in previous sections. It was one of the first direct-display-interactive devices and does provide a fairly rapid way of selecting CRT functions. There are, however, a number of drawbacks associated with light pen usage. There are numerous arm motions required, such as reaching to the pen storage position, unstoring the pen, moving the pen to the CRT screen, carefully aligning the pen on the target area, actuating the pen, and restoring the pen. No matter how the terminal is configured, the wire which connects the light pen to the decode logic circuit always seems to be in the way. Finally, the light pen itself is a fairly fragile item, and because it is subject to a great deal of handling and operator abuse, there are reliability problems with the device. Voice recognition is a new technology for computer system interaction. The operator speaks into a microphone and the computer program recognizes the human speech and interprets the command by reference to a function library. This technology has not yet reached a state of development where it can be placed into general use. Present state-of-the-art requires highly trained operators using specific vocabularies and carefully paced speech patterns. Present implementations of voice recognition technology are very expensive, thus it works against the basic design goal of reasonable system cost.

Touch panel technology appears to offer the greatest potential for providing a reasonable cost, effective, simple to use interactive interface. To use a touch panel, the operator simply touches a finger to the desired point on the CRT screen, and the touch panel locator decodes

the touched position and sends it to the computer. There are at least four different technological means of implementing a touch capability on a CRT screen: Crosswire overlay, voltage gradient substrate, echo ranging overlay, and beam interruption.<sup>6</sup>

- **Crosswire Overlay** - The crosswire overlay touch locator consists of vertically and horizontally spaced wires under tension forming a square matrix array. Typically, the wires are mounted approximately 3/8 inch apart. The vertical set of wires is separated from the horizontal set by a thick plastic sheet with holes at the crossovers. The entire matrix of crossed wires is enclosed between two plastic sheets which may be sealed to form an enclosed environment for the wires. When a finger presses against the outer sheet at a crossover, the outer sheet is deformed and the outer wire is pressed against the inner wire, making contact. Appropriate circuitry generates a digital output of the touch location. The crosswire overlay does not attenuate light from the CRT, however, this technology is not commercially available.
- **Voltage Gradient Substrate** - This sensitive position sensor consists of a curved glass sheet coated with a transparent resistive substrate, and a plastic cover sheet backed by a transparent conductive layer. Finger pressure causes contact between the conductive layer and the substrate. The conductive layer functions as a voltage probe for obtaining the corresponding X and Y coordinates from the substrate, and the voltages or ratios are digitized by an associated circuit board for transmission to the host processor. Resolution of 0.002 inch can be achieved by this technique, however, the overlay panel causes significant attenuation of light from the CRT display.

- **Echo Ranging Overlay** - The echo-ranging overlay system consists of two parts; a glass screen with integrated electronics mounted directly on the glass, and a separate digital controller which provides the processing and interface signals. Acoustic standing waves are generated by piezoelectric transducers located along the two sides of the digitizing surface to sense the position of an object in contact with the glass. An acoustic standing wave (Rayleigh wave) travels along the free boundary of a solid, much like a ripple on the surface of a pond. A user's touch sets up echo signals in both directions which are interpreted as the coordinates of the touch point. The acoustic waves are reflected by a passive probe and are used in an echo ranging system to convert the time taken for the acoustic echo to return into distance information for the target. Resolution for an echo ranging system is related to the spacing along two adjacent edges of the transducer and receiver pairs. This type of overlay must be kept clean and is subject to damage by scratching. Because the glass overlay is flat, there are parallax problems due to the curved CRT screen.
  
- **Beam Interruption** - A beam interruption overlay system uses scanning infrared beam technology. This technique does not place anything in the optical viewing path of the user; neither glass nor plastic covers the display face. IR-emitting diodes are mounted approximately 1/4 inch apart along two adjacent sides of a rectangular frame which fits the display perimeter. Photo detectors line the remaining two sides, producing a grid of infrared beams. The infrared beams intersected by the user's finger correspond to the coordinates of the touched point. The beam interruption system resolution depends on the spacing of the emitters and detectors. Parallax problems can be minimized by curving the rows of IR diodes and detectors to match the curvature of the CRT face.

Beam interruption technology is well developed, in general use in the field, relatively inexpensive, and reliable. For these reasons it is chosen as the means to implement the desired touch panel interactive capability.

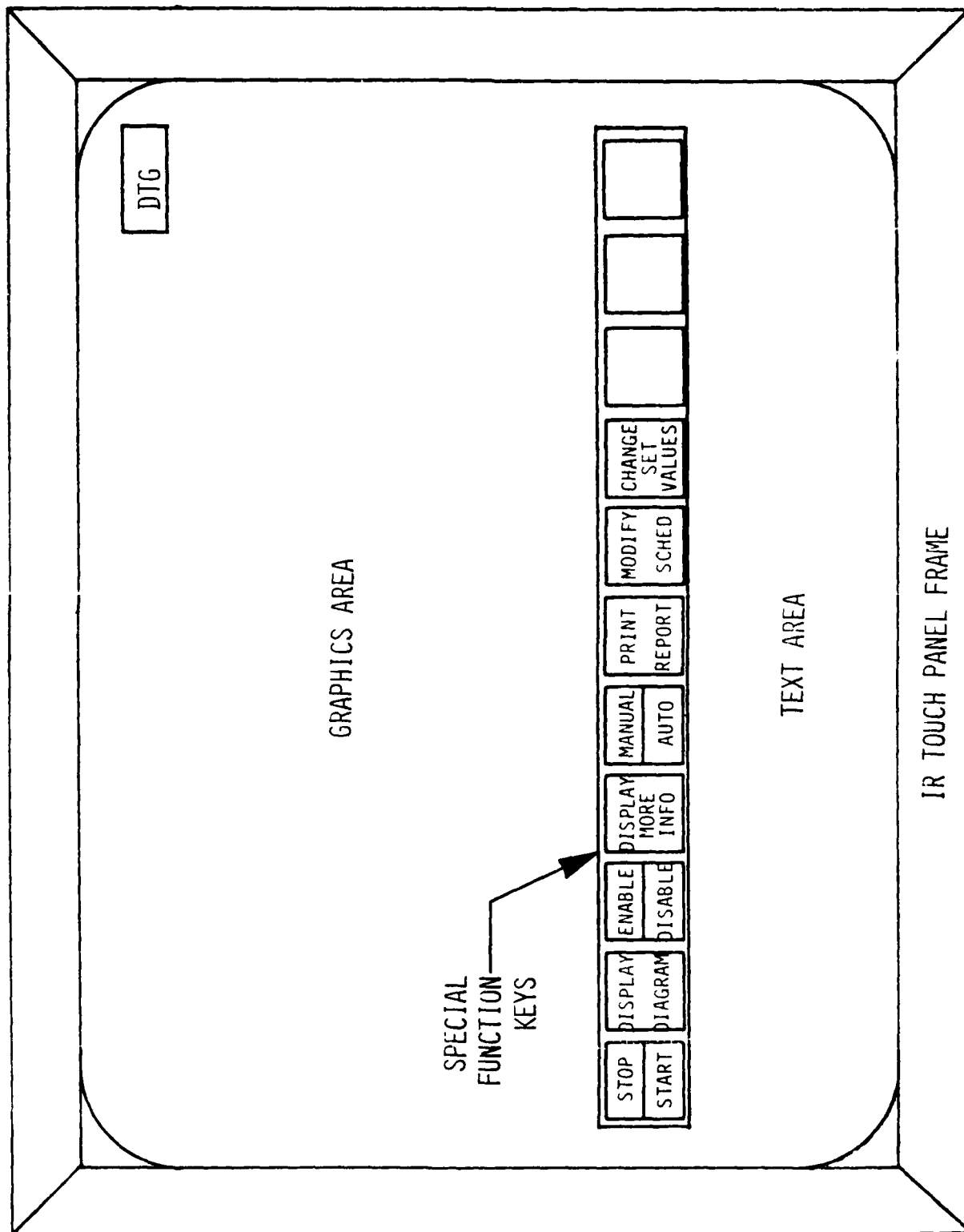
To summarize, the recommended form for the EMCS operator interface is a color graphics CRT with an infrared touch panel as the primary operator interaction device. The color-graphics display will include simplified system schematics similar to those contained in the EMCS Design Manual, and an alpha-numeric strip at the bottom for displaying necessary cues to the operator. A keyboard (with numeric keypad) is also included, because some of the operator functions cannot be accommodated by the CRT/touch panel combination without seriously complicating the operation of the interface and thereby making the interface less friendly and slowing interface reaction time. Inclusion of the keyboard will also maintain EMCS system flexibility by providing a capability for the lowest level operator terminal to be used for other purposes as required.

#### Interface Display Description

The physical layout of the graphics display is shown in Figure 2. The CRT screen is electronically divided up into four windows, labeled DTG, GRAPHICS AREA, SPECIAL FUNCTION KEYS, and TEXT AREA. The DTG window displays the current day, date, and time; the operators name; and the current temperature and dewpoint. The TEXT AREA window permits the display of textually formatted messages, mnemonics, cues, etc., to the operator. These two windows are not directly interactive with the touch panel feature.

The GRAPHICS AREA and SPECIAL FUNCTION KEYS windows are the major touch-panel interactive portions of the CRT display. The GRAPHICS AREA displays schematic-like diagrams of the HVAC system and components being controlled by the EMCS. Figure 4, taken from the Corps of Engineers draft EMCS Design Manual, is an example of the type of diagram which might be displayed. These graphics diagrams would be generated by installation A&E





IR TOUCH PANEL FRAME

Figure 3. Graphics Display Layout

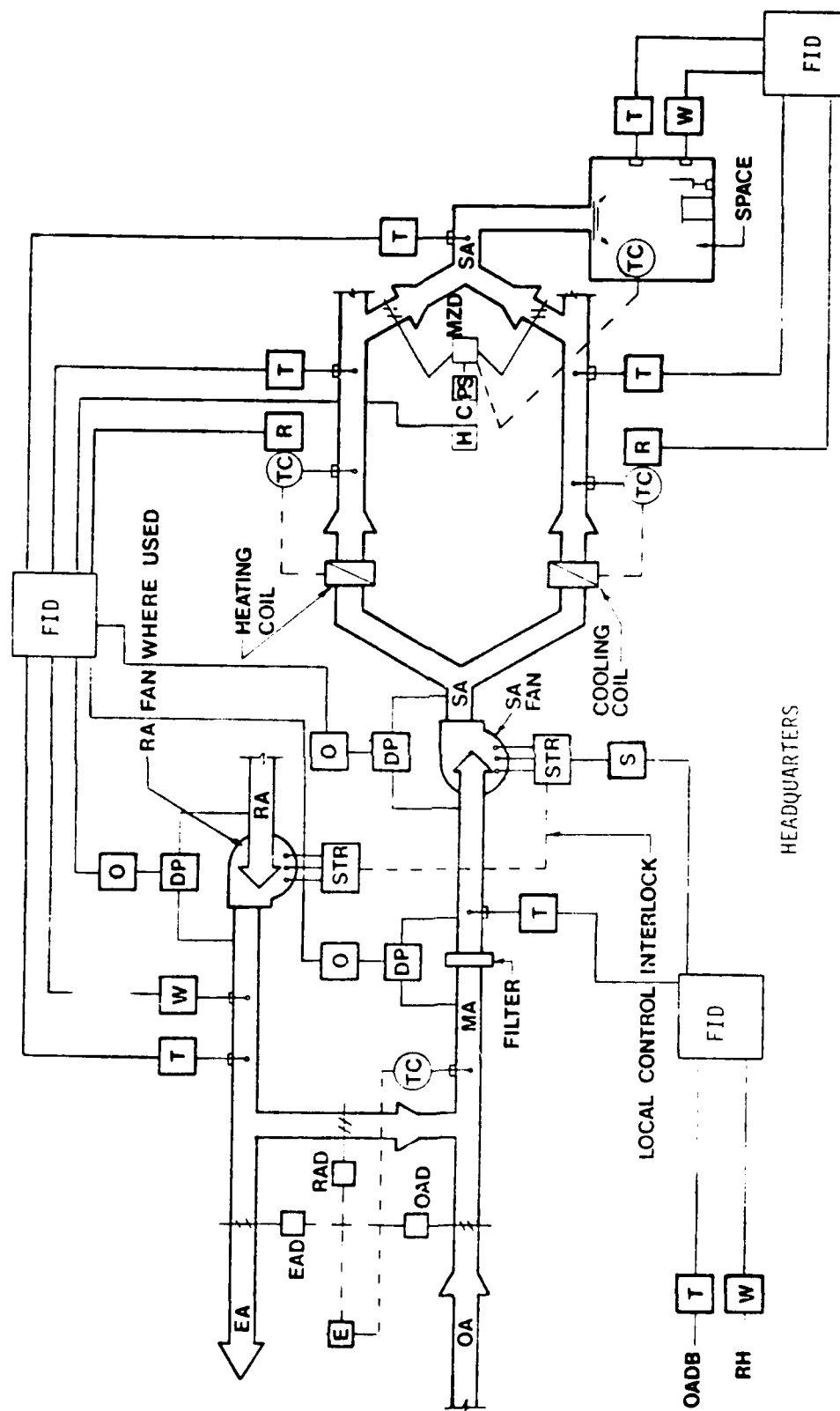


Figure 4. Sample System Diagram

personnel, using a simplified graphics generation capability included with the interface hardware/software package. Each diagram might represent a building, a data environment, or any other logical set or subset of points. The SPECIAL FUNCTION KEYS window will allow the implementation of user-defined special function keys to accomplish any appropriate operator task from the list described in previous sections. On a 19" diagonal measure tube, there is adequate space for about 11 keys with a target area  $3/4" \times 3/4"$  in size. The IR touch panel frame, which surrounds the CRT face, holds the IR-emitting diodes and photo detectors which form a grid of IR beams over the face of the CRT. Figure 5 shows an example of an IR-touch panel frame manufactured by Carroll Corporation.

#### Interface Operations

Operation of the interface will be discussed within the framework of required operator tasks, taken from the draft tri-service guide specification. The list of required operator tasks includes:

- (a) Request a display of any digital or analog point or any logical group of related points in the system.
- (b) Start up and shut down any selected systems or devices.
- (c) Initiate reports.
- (d) Request graphic displays.
- (e) Modify time and event scheduling.
- (f) Modify analog limits.
- (g) Adjust set points of selected controllers.
- (h) Select manual or automatic control modes.

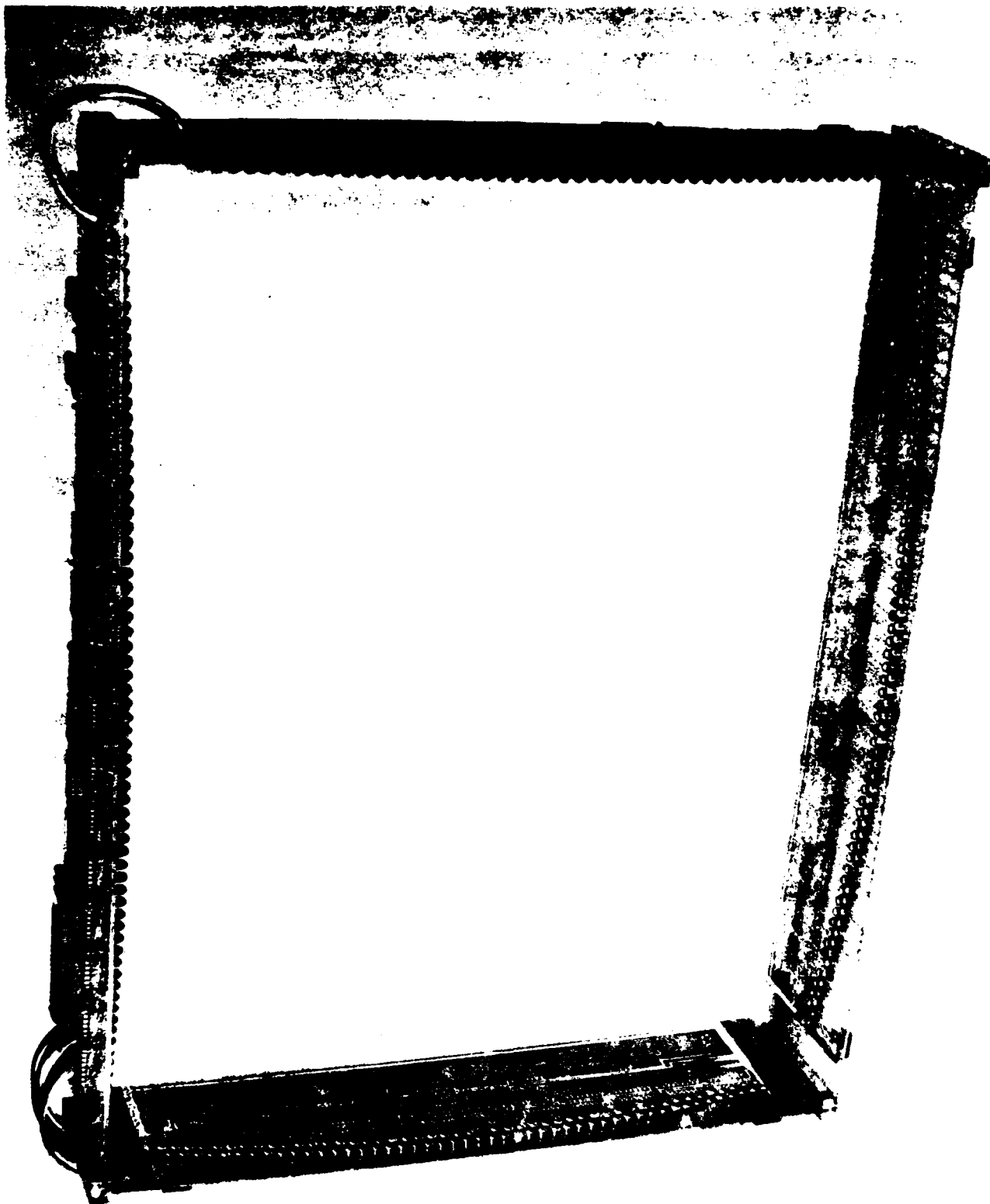


Figure 5. I-R Touch Panel Frame

## BUILDING DIAGRAMS

☐ BUILDING 106 LOWER

☐ BUILDING 106 UPPER

☐ HOSPITAL

☐ HEADQUARTERS

☐ TRANSPORTATION

☐ SUPPLY NO. 1

☐ SUPPLY NO. 2

☐ SUPPLY NO. 3

☐ HANGAR 1000

☐ PX-COMMISSARY

STOP

START

DISPLAY  
DIAGRAM

ENABLE  
DISABLE

DISPLAY  
MORE  
INFO

MANUAL  
AUTO

PRINT  
REPORT

MODIFY  
SCHED

CHANGE  
SET  
VALUES

-TOUCH SQUARE BESIDE DESIRED BUILDING

Figure 6. Diagram Selection Display

- (i) Enable and disable individual points. Disabling shall take precedence over all other actions.
- (j) Enable and disable individual FIDs.
- (k) Enable and disable individual MUX/IMUX panels.

With the proposed interface configuration, tasks (a) and (d) become one and the same. As described above, a "graphic display" and a "logical group of related points" corresponds to a schematic-like diagram of a portion of the HVAC system under control. To initiate these two tasks, there is a variable function key in the appropriate CRT display window labeled "Display Diagram". The operator touches the key with a finger, the key backlight illuminates to signal system reaction, and a table of diagram names appears in the GRAPHICS AREA window (see Figure 6). At the same time, a cue appears in the TEXT AREA window telling the operator to "Touch square beside described diagram name". Touching the selected square with a finger causes the GRAPHICS AREA and TEXT AREA windows to be erased, extinguishes the backlight on the "Display Diagram" key, and causes the selected graphics diagram to be drawn in the GRAPHICS AREA window. To display additional information on a given point or device contained in the schematic graphics diagram, there is a variable function key labeled "Display More Info". Touching this key with a finger causes the key backlight to illuminate, signaling system reaction, and a cue appears in the TEXT AREA window telling the operator to "Touch desired device symbol on diagram". When the operator touches the desired symbol, such as a temperature controller, the variable function key backlight is extinguished and all information appropriate to the device, such as set points, etc., is displayed in the TEXT AREA window.

Task (b) is accomplished with a split variable function key labeled "Start" and "Stop" (this task can be performed only when a schematic area diagram is displayed). To manually start a device such as a fan, the operator touches the "Start" section of the key. This action causes the touched section of the key to backlight, indicating system response, and displays a cue in the TEXT AREA window telling the operator to "Touch

desired device symbol on diagram". Touching the fan symbol in the diagram causes the symbol to be backlighted, indicating an on or energized state, extinguishes the backlight on the "Start" key, and erases the cue in the TEXT AREA window. The manual stop sequence for a device is conducted in the same way.

Task (c) is initiated by touching a variable function key labeled "Print Report". This action causes the "Print Report" key backlight to be illuminated, displays the set of possible reports in the GRAPHICS AREA window, and presents a cue in the TEXT AREA window telling the operator to "Touch square beside desired report". Touching the square causes the report to be generated and run, erases the GRAPHICS AREA and TEXT AREA windows, and extinguishes the backlight on the "Print Report" key.

Task (e) is initiated by touching a variable function key labeled "Modify Sched". This action backlights the key, displays a table of building or data environment names (see Figure 6) in the GRAPHICS AREA window, and presents a cue in the TEXT AREA window instructing the operator to "Touch the square beside the area name whose schedule is to be modified". Touching the desired square erases the GRAPHICS AREA and displays the operating schedule for the selected area. A series of cues in the TEXT AREA window will guide the operator through the process of scanning the schedule, selecting lines to be modified, entering parameter values through the numeric keypad, and closing out the schedule modification process.

Tasks (f) and (g) are performed in the same manner, by first touching a variable function key labeled "Change Set Values". These tasks can be performed only with a schematic area diagram displayed. The touched key is backlighted, and a cue is displayed in the TEXT AREA window telling the operator to "Touch the desired device symbol on the diagram". Touching the device symbol causes the adjustable parameters and their current values to be displayed in the TEXT AREA window. A series of cues guide the operator through the setting process, including entering parameter values through the numeric keypad and closing out the setting operation.

Task (h) is accomplished by a split variable function key labeled "Manual" and "Auto". To change operating mode the operator simply touches the desired area of the key, the EMCS shifts to the selected mode, and the backlight for the selected operating mode is illuminated.

Tasks (i), (j) and (k) are all accomplished in the same manner. These tasks can be performed only with a schematic area diagram displayed. There is a split variable function key labeled "Enable" and "Disable". To enable a point, FID or MUX, the operator touches the "Enable" area of the key. This action backlights the "Enable" key and displays a cue in the TEXT AREA window directing the operator to "Touch the desired device symbol on the diagram". Touching the desired symbol on the diagram enables that device, backlights the device symbol to indicate its active status, and extinguishes the backlight on the "Enable" key. "Disable" works in a similar manner.

#### Interface Characteristics

The EMCS man-machine interface implementation described above meets all of the goals for good interactive system design which were discussed in previous sections. The majority of the interaction between the operator and the system is accomplished by merely touching the CRT display with a finger. There is almost no typing required on the keyboard and the few parameter values required are entered via a numeric key pad. The CRT display shows schematic like system diagrams which are familiar to HVAC engineers and mechanics, and has operator cues which are phrased in simple English. Thus, the EMCS interface itself takes on a very large degree of transparency to the operator, giving the desirable impression that the operator is controlling the HVAC system, not the EMCS.



### Additional Interface Requirements

The foregoing discussion referred almost exclusively to the lowest level system operator. The next higher level of operator is the professional A&E who is required to produce graphics diagrams and make changes to automatic control algorithms. Generation of system graphic diagrams is most easily accomplished using a combination of hardware and software features which will allow generation of a symbol library and ease the task of building a diagram. The interface hardware must be equipped with necessary graphics implementing capabilities to ensure rapid drawing of graphics. The graphics generation capability could be acquired on a system by system basis, or it could be developed separately as a standard and specified for all system installations. Specification of a standard graphics package or language has the potential to save considerable sums of money over the acquisition of great numbers of systems.

Because there are operators on the EMCS with varying levels of skill and required operations, there needs to be some type of system access restriction. The draft tri-service guide specification calls for eight levels of access, each with password protection. This seems to be an unnecessary complication in that only three levels of operators have been defined. It should be adequate to provide three levels of access, wherein each system operator is restricted to use of an explicitly defined subset of system commands. Honeywell's Delta 5600 system has passwords incorporated into the software, so that when an operator logs on with a name and a secret code number unique to that name, the system controls operator access level automatically.

## SECTION VI. RECOMMENDATIONS

Based upon the research conducted and reported in this report, the following recommendations are offered.

- Modify the tri-service guide specification to incorporate the EMCS man-machine interface defined herein.
- Modify the tri-service guide specification to include three levels of operator access and use embedded passwords as in the Delta 5600 design.

## REFERENCES

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- 5 Miller, G.A., "The Magical Number Seven, Plus or Minus Two: Some Limits on our Capacity for Processing Information", Psychological Review 63, (1956), 81-97.
- 6 Walthour, L., Prince, M.D., "A Survey of Soft-Controllable Touch Panels for 1990's Transport Aircraft Research Simulators", Lockheed-Georgia Company, Marietta, Georgia.

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